Original TF03008

Confidential

University of Illinois at Urbana-Champaign
Invention Disclosure Form

General Instructions

The purpose of the disclosure form is to provide a written dated record of your invention disclosure and to provide information from which your technology can be evaluated as to its patent and commercial potential. A disclosure also is necessary to enable the University to comply with most industrial contract requirements as well as the requirement of the U.S. federal government laws and regulations as they are applied to university grants and contracts. The following information will be helpful to you when completing the attached forms.

- DO NOT MODIFY THE FORM. If questions do not apply, so indicate with "NA." Add spaces and table rows as needed.
- An invention disclosure should be completed when something new and useful has been conceived or developed, or when unusual, unexpected or unobvious research results have been achieved and can be utilized. In accordance with the University of Illinois General Rules Concerning University Organization and Procedure, Article III (Section 7a),

  > *All intellectual property in which the University has an ownership interest under the provisions of this policy and that has the potential to be brought into practical use for public benefit or for which disclosure is required by law shall be reported promptly in writing by the creator(s) to the designated campus officer through the appropriate unit executive officer(s) using the disclosure form provided by the campus.*

- The purpose of the disclosure is to provide detailed information about the technology, to cite any relevant sponsorship and publication information that will enable the Office of Technology Management (OTM) and outside counsel to determine if the technology is patentable, and to identify possible opportunities for licensing and commercializing the technology.
- Identifying all individuals who contributed to or worked on the technology is very important. Inventorship is defined by U.S. patent laws and is usually determined at the time a patent application is filed. When completing the disclosure form, please list all individuals who contributed to the conception or development of the technology.
- After the OTM receives the completed signed disclosure, the OTM will review it and contact the inventors shortly thereafter to arrange a meeting to discuss the disclosure and the technology.
- If additional space is needed to complete this form, please add or provide information in the form of an attachment.

For advice on completing the disclosure form or for additional information, contact the OTM. Return the *completed and signed* disclosure along with supporting documentation to:

Office of Technology Management
University of Illinois at Urbana-Champaign
319 Ceramics Building (MC-243)
105 South Goodwin Avenue ◆ Urbana, IL 61801
(217) 333-7862 ph ◆ (217) 265-5530 fx
otm@uiuc.edu

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Confidential Invention Disclosure — University of Illinois at Urbana-Champaign

1. TITLE OF INVENTION (*non-enabling, yet descriptive and concise*):

System for blind determination of reverberation time in unknown acoustic environments using passively received sounds.

2. NON-CONFIDENTIAL DESCRIPTION
Provide a brief, non-enabling description of the invention and identify keywords that describe your invention.

The invention is a system for determining the reverberation time in an unknown acoustic environment utilizing a single microphone and passively received sounds. Reverberation time of the listening environment is determined using a blind estimation algorithm that incorporates a maximum-likelihood estimator followed by an order-statistics filter.

3. INVENTOR(S):
Inventorship is determined by criteria specified in U.S. patent law. A legal inventor is generally someone who has conceived or contributed to an essential part of the invention, either independently or jointly with others during the development or conception of the technology or the technology's reduction to practice. Final inventorship is determined by patent counsel at the time the patent application is filed.

Please list all those who worked on the technology and describe their contribution to the invention. ***If any person holds a joint appointment with any other university, a company or governmental agency, or the like, please note that fact.***

INVENTOR:

Name: Rama Ratnam
Dept/Unit Affiliations: Beckman Institute
Address-Work: Beckman Institute for Advanced Science and Technology, Univ. Illinois
Phone: 217-244-3067 Fax: 217-244-5180 Email: ratnam@uiuc.edu
Address-Home: 613 W. Springfield Ave., Apt. 4, Champaign, IL 61820
Citizenship: India
Contribution: Dr. Rama Ratnam is a research engineer with the Intelligent Hearing Aid Project. He was responsible for the derivation of the maximum-likelihood equations, developing the order-statistics filter used for selecting the most likely RT from the estimates, and the implementation of the system.

INVENTOR:

Name: Albert S. Feng
Dept/Unit Affiliations: Beckman Institute / Dept. of Molecular and Integrative Physiology
Address-Work: Beckman Institute for Advanced Science and Technology, Univ. Illinois
Phone: 217-244-1951 Fax: 217-244-5180 Email: a-feng@uiuc.edu
Address-Home: 1209 Wilshire Court, Champaign, IL 61821
Citizenship: U. S.
Contribution: Dr. Albert Feng has been the team leader since 1993. He identified the problem and its importance, and has been responsible for recruiting other team members. He secured for the principal means of support from the Beckman Institute, recruited the faculty team,

and was central to the construction of the experimental laboratory and the management of overall team work.

INVENTOR:

Name: Douglas L. Jones
Dept/Unit Affiliations: Beckman / ECE / CSL
Address-Work: Beckman Institute for Advance Science and Technology, Univ. Illinois
Phone: 217-244-6823 Fax: 217-244-1642 Email: d-jones@csl.uiuc.edu
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Citizenship: U. S.
Contribution: Dr. Douglas Jones first suggested the use of a maximum-likelihood estimator utilizing passively received sounds for estimating the reverberation time of listening environments. He has been the technical advisor on the theory and implementation of this system.

INVENTOR:

Name: Charissa R. Lansing
Dept/Unit Affiliations: Beckman Institute / Dept. of Speech and Hearing Science
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Phone: 217-244-2539 Fax: 217-244-1598 Email: crl@uiuc.edu
Address-Home: 2903 Valley Brook Drive, Champaign, IL 61821
Citizenship: U. S.
Contribution: Dr. Charissa Lansing has contributed most importantly by referencing all project suggestions to current practice in hearing aid design and use, as well as to the psychoacoustics of hearing and speech perception. This information has helped determine overall design parameters for simulation and testing. Dr. Lansing was an early participant in the project, starting in January of 1994.

INVENTOR:

Name: William D. O'Brien
Dept/Unit Affiliations: Beckman Institute / ECE
Address-Work: Beckman Institute for Advanced Science and Technology, Univ. Illinois
Phone: 217-333-2407 Fax: 217-244-0105 Email: obrien@angst.brl.uiuc.edu
Address-Home: 2002 O'Donnell Drive, Champaign, IL 61821
Citizenship: U. S.
Contribution: Dr. William O'Brien joined the group in August of 1995. He has introduced to the project an understanding of physical acoustics. He has played a substantial role in critiquing the ongoing laboratory measurements, as well as in defining priorities for both theoretical and experimental efforts.

INVENTOR:

Name:
Dept/Unit Affiliations:

Address-Work:

Phone:

Address-Home:

Citizenship:

Contribution:

5. PRIOR ART

Cite known publications and patents of others believed by you to disclose ideas most closely related to the invention (attach copies, if available):

(a). Attias, H., Schreiner C. E. (1998), "Blind source separation and deconvolution: The dynamic component analysis algorithm," Neural Comp. 10: 1373-1424.

(b). Bell, A. J., Sejnowski, T. J. (1995), "An information maximization approach to blind source separation and blind deconvolution," Neural Comp. 7: 1129-1159.

(c) Chu, W. T. (1978), "Comparison of reverberation measurements using Schroeder's method and decay curve averaging method," J. Acoust. Soc. Amer. 63(4): 1444-1450.

(d) Cox, T. J., Li, F., and Darlington, P. (2001), "Extracting room reverberation time from speech using artificial neural networks," J. Audio Eng. Soc. 49(4): 219-230.

(e) Cremer, L., Muller, H. (1978), "Principles and Applications of Room Acoustics", T. Schultz (Transl.,) Vol. I. London: Applied Science

(f) Lebart, K., Boucher, J. M., and Denbigh, P. N. (2001), "A new method based on spectral subtraction for speech dereverberation," Acustica 87: 359-366

(g) Nannariello, J., Fricke, F. (1999), "The prediction of reverberation time using neural network analysis," Appl. Acoust. 58: 305-325.

(h). Sabine, W. C. (1922), "Collected Papers on Acoustics," Cambridge: Harvard University Press.

(i) Schroeder, M. R. (1965), "New method for measuring reverberation time," J. Acoust. Soc. Amer. 37: 409-412.

(j) Schroeder, M. R. (1966), "Complementarity of sound buildup and decay," J. Acoust. Soc. Amer. 40(3): 549-551.

(k) Tahara, Y., Miyajima, T. (1998), "A new approach to optimum reverberation time characteristics," Appl. Acoust. 54: 113-129

(l) Xiang, N. (1995), "Evaluation of reverberation times using a nonlinear regression approach," J. Acoust. Soc. Amer. 98(4): 2112-2121

6. SPONSORSHIP

Identify all grants, contracts, and other sources of funds contributing to or <u>possibly</u> contributing to the conception and/or development of the invention. Please note that accurate and complete sponsorship information is required to fulfill UIUC obligations under research grants and contracts.

7. FUTURE FUNDING

If work on the invention is to be continued, indicate known or probable sources of funding and the nature of the work yet to be performed.

8. GENERAL SUMMARY OF THE INVENTION

Please provide a brief summary of the invention, addressing: What is the purpose of the invention? Is it a new product, process, or composition of matter? Is it a new use for or improvement to an existing product, process or composition of matter?

The invention is a system consisting of 1) a single sensor for receiving acoustic signals, and 2) a processing unit that executes a maximum-likelihood estimation algorithm, followed by an order-statistics filter to determine the reverberation time of the acoustic environment blindly. The processing can be in a single wide-band channel, or in multiple narrow-band channels followed by an averaging of the estimates from each channel. The system is a new method for the determination of reverberation time when the auditory environment, the geometry of the enclosed space, and acoustic signals are unknown.

9. PRIOR METHODS OR APPARATUS

How long has the problem addressed by this technology existed? Provide a full and complete description of the closest known prior methods or apparatus and any disadvantages or problems of each that are solved by the present invention. Attach any materials, such as publications, advertisements, or patents of others, that you have or that are reasonably available to you concerning the known prior methods or apparatus.

The estimation of room reverberation time (RT) has existed in the field of engineering and architectural acoustics for a long time. The RT of a room specifies the duration for which a sound persists after it is no longer present, due to the multiple reflections of sound from the various surfaces within the room. RT is commonly referred to as the T_{60} time since the accepted measure of persistence of sound is the time to decay 60 dB below its peak value. The RT of a room provides a measure of the listening quality of the room. For speech, it has been noted that the intelligibility reduces as the RT increases.

In the early 20th century, Sabine (reference (h)) provided an empirical formula for the explicit determination of RT based solely on the geometry of the environment and the absorptive characteristics of its surfaces. Since then, Sabine's reverberation time equation has been extensively modified and its accuracy improved, so that today, it finds use in a number of commercial software packages for the acoustic design of interiors. Formulae for calculation of RT are used primarily for the design of concert halls, classrooms, and other acoustic spaces where the quality of the received sound is of greatest importance, and the extent of reverberation has to be controlled. However, in order to determine the RT of existing environments, both the geometry and the absorptive characteristics have to be first determined. When these cannot be easily determined, it is necessary to search for other methods, such as those based purely on the recordings of sounds in the environment to be tested.

In 1965, Schroeder (reference (i)) presented a method for estimating RT based solely on the recording of an acoustic signal, radiated into the test enclosure. The method obviated some of the problems occurring in situations where the geometry and surface absorption characteristics are unknown. A burst of broad- or narrow-band noise was radiated into the test enclosure until it

reached steady state, and was then abruptly switched off. The method tracks the sound energy decay following sound cessation. This method, referred to as Schroeder's backward integration method, while theoretically and practically important, has some limitations. Specifically, the sound used for measuring RT must be stationary and uncorrelated, and the precise time of sound offset must be known.

While Schroeder's method has been improved over the years (references (c), (l)), the improvements do not lift the restrictions placed on the applicability of Schroeder's method. At present, a "blind" method that requires no knowledge of the geometry, absorptive characteristics, and sound source characteristics or offset time of the sound is unavailable. Partially blind methods have been developed where the characteristics of the room are "learned" using neural network approaches (references (d), (g), (k)), or where some form of segmentation procedure is used for detecting gaps in sounds so that the sound decay curve can be tracked (reference (f)). The only other method that may be described as truly blind is "blind deconvolution", where sound source recovery is attempted by deconvolving the room output with the unknown room impulse response (references (a), (b)). In principle, this method can be used for extracting the RT, but there is a serious drawback that limits its applicability. Namely, the room impulse response must be minimum phase, a condition that is rarely satisfied.

The invention attempts to address several of the drawbacks found in existing methods. It does not require that a test signal be radiated into the test enclosure (as in Schroeder's method) or that the geometry and absorption characteristics of the test enclosure be known (as with the Sabine type formulae). The system performs blind estimation based on a decay curve model describing the reverberation characteristics of the enclosure. Sounds in the test enclosure (speech, music, or other pre-existing sounds) are continuously processed and a running estimate of the reverberation time is produced by the system. A decision-making step then collects estimates of RT over a period of time and arrives at the most likely RT using an order-statistics filter.

10. DISADVANTAGES OR LIMITATIONS

Indicate any disadvantages or limitations of your invention. Explain how they might be overcome.

The invention may be susceptible to errors under the following conditions: 1) When sounds in the ambience do not have sufficient number and duration of pauses or periods of silence where the decay can be tracked (as can occur in extremely noisy conditions where there are many sound sources) because the invention assumes that periods of silences generally occur in natural listening conditions, and makes decisions based on this assumption. 2) The offsets of sound segments are gradual rather than abrupt (for example certain music sounds) in which case the system over-estimates the room RT. In this case, a strategy is presented for extracting the most likely RT based on a long-term history of the estimates.

11. BEST MODEL

Give a complete detailed description of the best model for practicing your invention. Provide data or other evidence of the feasibility or operability of the invention. Attach any visual material that may be available, such as: sketches, graphs, drawings or photographs. Indicate any alternate embodiments, procedures or methods of construction for the invention.

Currently, Schroeder's method (reference (i)) represents the best model for estimating room reverberation time using a sound with a known offset time. However, our system/algorithm (Appendix A) is the method of choice when the sound offsets are not known. This new system/algorithm is hereafter referred to as the maximum-likelihood reverberation time estimator (MLRTE), and is described in detail in Appendix A.

The method can effectively estimate the reverberation time of any listening environment where single microphone recordings are available. The method is "blind" and so no further information about the acoustic environment or the sound sources is necessary. It can be incorporated in a device such as a hearing aid for deciding on the optimal signal processing strategies in different listening rooms, in a sound-level meter used for characterizing the acoustic environment, or in any device that requires information about the acoustic environment. Further, the system can be used in single or multiple channels, for off-line as well as on-line analysis of the acoustic environments.

12. STAGE OF DEVELOPMENT

Describe the development status (concept only, laboratory tested, prototype, etc.). Indicate what further development may be necessary.

The MLRTE procedure has been tested in a variety of real listening environments using an off-line procedure based on single-microphone data. It has been tested in both single- and multi-channel versions. To verify its applicability in on-line situations two issues need to be addressed. First, a real-time implementation of the algorithm is necessary to evaluate the system in a large number of acoustical environments. Second, the time taken for generating a reliable estimate of the reverberation time in real-time implementations needs to be assessed. This is necessary if the system is employed in situations where the acoustical environment is changing rapidly, as for instance when the system is implemented on a device that is in motion.

13. POTENTIAL LICENSEES

List any potential licensees or end users that may be interested in this technology.

Phonak AG expressed potential interest in licensing this technology.

14. THE DISCLOSURE SHOULD BE SIGNED AND DATED BY THE INVENTOR(S), AND THEN READ AND SIGNED BY A NON-INVENTOR WITNESS.

I (We) hereby agree to assign all right, title and interest to this invention to UI and agree to execute all documents as requested, assigning to UI our rights in any patent application filed on this invention, and to cooperate with the RTMO in the protection of this invention. UI will share any royalty income derived from the invention with the inventor(s) according to the General Rules, Article III, Section 8.

Inventor(s) Signature	Date	Witness
[signature]	Jan 31, '03	Michael E. Lutomski
Albert S. Feng	Jan 31, '03	Michael E. Lutomski
Douglas L. Jones	01/31/03	Judy L. Whittington
Chdussa Jonas	01/31/03	Judy L Whittington

W O'Brien	2/5/03	Judy L Whittington

Unit Executive Officer(s) Signature	Date	Printed Name & Unit
	2/6/03	Jennifer Quirk/Backman

DISTRIBUTION *Prepare and distribute copies of the completed Invention Disclosure Form as follows:*
1 copy for each Inventor's file
1 copy to each Unit Executive Officer
1 original and 2 copies to the Office of Technology Management, 319 Ceramics Building, 105 South Goodwin Avenue, Urbana, IL 61801 (MC-243)

✓ **CHECKLIST FOR COMPLETION OF INVENTION DISCLOSURE FORM:**
- ☐ Attach supplemental materials, such as copies of the inventor's oral or written publications
- ☐ Attach copies of publications or patents closely related to the invention enclosed
- ☐ Provide grant or contract numbers along with UFAS account numbers
- ☐ Obtain signatures of all inventors, the Unit Executive Officers, and witnesses
- ☐ Enclose 2 copies and the original disclosure form for the OTM, and distribute other copies as specified